HYBRID WIRELESS COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

1.   Field of the Invention

[0001]   The present invention relates to the field of fixed, wireless communication systems, and in particular to a hybrid modulation technique for point to multi-point communications between a series of base stations and a plurality of sets of fixed remote users, each set communicating directly with one of the base stations for connection to a wide area network such as the Internet.

2.   Description of the Prior Art

[0002]   A new information revolution has created a burgeoning demand for network communications. Multimedia services, including the Internet, have emerged as exceptional new sources for distribution of video, voice and data information having business, educational and cultural content. Recent deregulation by the United States Government has opened new competition in local network access markets. Technologies providing the so-called "last mile" network connection to millions of domestic households have become one of the fastest growing fields in telecommunications. Traditionally, the "last-mile" market was dominated and divided by incumbent local telephone companies for voice service and cable television operators for video service. This situation has dramatically changed as a result of the recent, explosive growth in Internet usage. With data and services migrating toward "digitized" or "digital"

communication, a full, packet-based network with integrated video, voice, and data is close to reality. As a result of this trend, through innovative network architectures with new wired or wireless solutions, service providers could offer many alternatives to traditional services.

[0003]   Wireless networks became popular in the 1990's initially in order to serve mobile users. However, the same or similar technology can be used to provide wireless Internet access for fixed users; the advantage of wireless over wired access methods like cable and direct subscriber lines (DSL) is that wireless networks can be deployed more quickly and potentially at lower cost. In order to serve homes and small businesses, the network must be designed to support a large number of users in the limited spectrum available for fixed wireless services. It must be implemented at low cost. Thus cost and capacity are primary considerations in setting up an economically viable, wireless access scheme for home and small business users.

[0004]   The problem of providing a relatively inexpensive method and system for access by fixed users of multimedia services through a shared spectrum, particularly one having a wide band, wireless link, has presented a major challenge to the telecommunications industry.

[0005]   Conventional techniques include many variations of both TDMA and CDMA approaches to point to multi-point communications, each of which has its own particular limitations including problems with bandwidth, data rate, interference and costs to produce, install and operate.

[0006]   What is needed is an approach to providing such communications that balances the advantages and

disadvantages to known techniques to provide a robust wideband and inexpensive installation.

SUMMARY OF THE INVENTION

[0007]   In accordance with a first aspect of the present invention, a method of wideband communication between a base station and a plurality of remote terminals within each cell of a multicell network is provided in which a downlink data stream from the base station to the remote terminals is modulated in a plurality of channels that are time division multiplexed into a downlink signal that is subsequently spread with a pseudo-random noise signal to form a broadcast signal; and an uplink data stream from each remote terminal is modulated in one or more channels that are each then spread with an orthogonal code and summed to form an uplink signal for synchronous transmission with the other terminals in the cell to the cell base station.

[0008]   In another aspect, the present invention provides a wideband multi-cell network, wherein each cell includes a base station and a plurality of remote terminals; each base station having logic for processing an input data signal for broadcast to remote terminals in the same cell comprising a demultiplexer for demultiplexing the input data signal into a plurality of channels, a plurality of modulators for modulating a portion of the input data signal in each channel, a multiplexer for time division multiplexing each modulated channel to form an output data signal, a multiplier for spreading the output data signal with a pseudo-random noise signal to form a broadcast signal, and a RF system for broadcasting the broadcast signal to be received by the plurality of remote terminals within the same

cell; and each remote terminal having logic for processing a data signal for transmission to the base in the same cell comprising a demultiplexer for demultiplexing the data signal into one or more channels, a modulator in each channel for modulating a portion of the data signal in each channel, a multiplier for spreading each modulated channel with an orthogonal code to form an orthogonal signal, an adder for summing a predetermined number of the orthogonal signals to form a terminal signal, and logic for scheduling the terminal signal for transmission by the remote terminal to be received by the base station in the same cell synchronously with terminal signals from other remote terminals in the same cell.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]   Figure 1 is a block diagram of a point to multi-point, broadband network according to the present invention;

[0010]   Figure 2 is a schematic diagram of an embodiment of one frame of time division duplex (TDD) data traffic carried on the network of Figure 1;

[0011]   Figure 3a and 3b is an expanded, schematic view of the time frame of Figure 2, showing downlink and uplink segments further divided into time slots during which packets of data are transmitted;

[0012]   Figure 4a and 4b is a block diagram of an embodiment of the transmission logic for the base station of Figure 1;

[0013]   Figure 5 is a block diagram for a convolutional encoder for use in the transmission logic of Figure 5;

[0014]   Figure 6 is a block diagram for an interleaver for use in the transmission logic of Figure 5;

[0015]   Figure 7 is a schematic diagram of signal constellations available to QPSK, QAM8 and QAM16 modulation processes for use in the transmission logic of Figure 5; and

[0016]   Figure 8 is a block diagram of an embodiment of the transmission logic for a remote terminal as shown in Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

[0017]   A broadband wireless access (BWA) system, according to the present invention, uses a traditional cellular structure, consisting of multiple base stations or cell sites, each serving a plurality of remote terminals in its coverage area. Each base station may be connected to one or more networks such as the Internet backbone, telephone, television, etc. in a variety of ways.

[0018]   The present invention utilizes a first modulation technique in the downlink direction from the base stations to the remote terminals and a second, different modulation technique in the uplink direction from the remote users to the base stations.

[0019]   In a preferred embodiment, the downlink from a base station to multiple remote terminals may use a single data channel or data stream. The single data stream may be de-multiplexed into a number of encoding and modulation channels related to the number of remote terminals, such as 32. The modulation channels are quadrature phase shifted (QPSK) or quadrature amplitude modulated (QAM). Time division multiplexing (TDM) is then used to combine the channels for transmission. The combination of the channels is filtered and

spread with a pseudo-random noise (PN) signal prior to transmitting in a time division duplexing (TDD) scheme.

[0020]   In accordance with the present invention, one or more data channels may be assigned to any one user and transmitted on the uplink from the remote terminal to the respective base station in a synchronous, orthogonal code division multiple access (O-CDMA) scheme within allocated time slots to serve multiple users. The codes employed are short (relative to the long PN code sequences) orthogonal sequences that eliminate interference between the different user signals received synchronously at the base station, and that provide sufficiently low cross-correlation with signals received from users communicating with neighboring bases to also minimize or eliminate inter-base interference. This technique differs from conventional CDMA techniques in that a PN code is not used to spread the frequency of the uplink transmissions.

[0021]   In accordance with the present invention, the forward links and return links, that is, the downlinks and uplinks, operate on the same carrier frequency, using time division duplexing (TDD). Because the forward and return link waveforms are relatively similar in structure to each other even though different modulation schemes are used, the implementation of the chipsets used in equipment for both directions of propagation becomes almost identical, leading to economies of scale, which can be passed on to the ultimate users.

[0022]   Encoding used in both downlink and uplink directions can be either convolutional, as proposed in a preferred embodiment, or an alternate error-correction code. Each of these codes has advantages and disadvantages, mainly in terms of trading coding gain for complexity and delay.

[0023]   With reference now to Figure 1, a pair of cells **10** and **11** are shown in accordance with the present invention.   In a point-to-multipoint wireless network cell according to the invention, all remote terminals **14** in one particular cell **10** share the inbound or uplink segment of wireless link **15** with their assigned base station **20**. Cell **11** may be configured in the same manner as cell **10**.   The base station **20** of each of a plurality of cells is further connected to the Internet or other network through link **18**. Wireless link **15** may include a single wireless channel that is time shared between downlink segment and the uplink segment using time division duplexing (TDD). Downlink communications to each of the remote terminals **14** is accomplished through a combination of TDM and TDD on the wireless channel, and uplink communications from each remote terminal shares the channel using a combination of TDMA and O-CDMA. The downlink from the base modulates a single carrier signal that is broadcast to all remote terminals, and each remote terminal uplink modulates its own carrier signal thus resulting in multiple uplink carriers.

[0024]   Referring now to Figure 2, the underlying modulation of signals in both the uplink **24** and downlink **23** segments of link **15** can be selected by a network management process based on traffic, signal-to-noise, and interference conditions on the link **15**. The modulation methods used in a preferred embodiment include quadrature phase shift keying (QPSK) with rate-½ and rate-¾ convolutional coding; 8-ary quadrature amplitude modulation (8QAM) with encoding rate ⅔; and 16-ary quadrature amplitude modulation (16QAM) with encoding rate ¾. However, it is clear that, if even higher capacity is desired, higher-order modulation schemes (such as 64-ary QAM or other) can be used as well.

[0025]   Figure 2 shows one time frame **22** of TDD traffic carried on the wireless link **15**. The time frame **22** is divided into a downlink segment **23** and an uplink segment **24**. The duration of the downlink segment **23** and uplink segment **24** can be varied from one time frame **22** to the next to adapt to the data flow requirements within the cell.

[0026]   Referring now also to Figure 3a, each segment **23**, **24** is further divided into time slots **26** and **27**, respectively, during which packets of information are transmitted. Downlink signals are broadcast by base 20 to all remote terminals **14** assigned to the base **20**, and each downlink time slot **26** carries the multiplexed data channels for a preselected number of remote terminals.

[0027]   With reference now to Figure 3b, the data broadcast during each downlink time slot **26** is time division multiplexed (TDM) between all the remote terminals to which the particular downlink slot period is addressed. In an exemplary embodiment wherein QPSK, rate-1/2 modulation is employed, each downlink segment **23** may be divided into a maximum of N = 7 downlink time slots **26**; each time slot may then be further divided into 24 synchronization time periods and 576 data time periods. Each downlink data time period **29** may then be divided into 32 pulse positions, each of which carries a symbol corresponding to a modulated data word processed by one of the code channels **48** (see discussion below). Each symbol may carry between 1 to 3 information bits depending upon the modulation scheme employed.

[0028]   Each pulse position thus carries data for one of the 32 data channels **48**, and thus the 32 user data channels are time division multiplexed (TDM) within each downlink data time period **29**. The signal broadcast by the base and carried on the downlink is received continuously by

all remote terminals, and each individual remote terminal extracts its intended data bits from the received signal.

[0029]   With reference now again to Figure 3a, each uplink time slot **27** is further divided into a plurality of orthogonal code channels **31**, preferably 32 channels in accordance with the exemplary embodiment being described, corresponding to the remote terminals assigned to the particular time slot period. The remote terminals grouped in one such uplink time slot **27** synchronize their TDMA transmissions to transmit only during their assigned uplink time slots such that their signals are received at the base station synchronously to be aggregated into a multiplexed received signal for demultiplexing.

[0030]   Each time slot **26, 27** includes a synchronization portion followed by a data portion (e.g. the 24 synchronization time periods and 576 data time periods mentioned above and shown in Figure 3b). The allocation of the downlink **23** and uplink **24** frame-segment boundaries is flexible and can be varied by the network planner or administrator based on any detected asymmetry of the traffic demand. Guard-time intervals **25** (as shown in Figure 2) are inserted between the downlink-uplink and uplink-downlink transitions to eliminate interference between the links due to finite delays of signal propagation.

[0031]   The waveform parameters used in a preferred embodiment are summarized for the downlink **23** and uplink **24** segments in Table 1. A frame length of 7.5 milliseconds provides 2,025 chips to be used for guard intervals between the downlink **23** and uplink **24** segments.

Table 1. A Preferred Time Frame Structure

Parameter/ modulation	QPSK; $r=\frac{1}{2}$	QPSK; $r=\frac{3}{4}$	QAM8; $r=\frac{2}{3}$	QAM16; $r=\frac{3}{4}$

method				
Bps/Hz	1	1.5	2	3
Slot size (bytes)	72	72	72	72
Slot size (bits)	576	576	576	576
Slot size (symbols)	576	384	288	192
Synch bytes	3	3	3	3
Synch symbols	24	16	12	8
Total symbols	600	400	300	200
Slots/frame	8	12	16	24
Chip rate (Mcps)	20.75	20.75	20.75	20.75
Aggregate data rate (Mbps)	20.48	30.72	40.96	61.44
Frame length (ms)	7.5	7.5	7.5	7.5

Downlink

[0032]   Figure 4a is a block diagram depicting the preferred transmission logic **40** for one base station **20**, as shown in Figure 1. The transmitter logic **40** consists of a plurality of code channels **48**$_{(0-n)}$, preferably 32 such channels, that are summed together, filtered, and up-converted to an RF carrier. The input **42** to the transmission logic **40** is a single 32-bit word stream of time division multiplexed packets. The word stream is de-multiplexed by demultiplexer **46** into the code channels **48**$_{(0-31)}$.   Each code channel **48** processes a block of six N-bit (in the preferred embodiment, 32-bit) words, or 24 bytes, before the demultiplexer **46** switches to the next code channel **48**. Each channel **48** converts each 32-bit word into a bit stream through parallel-to-serial converter **50** for subsequent forward error correction (FEC) **44**, the preferred embodiment being convolutional encoding, and interleaving. The convolutional encoder **52** has a preferred constraint length of 9 and an encoding rate of ½. Certain encoded bits are deleted to produce encoding rates of ⅔ and ¾. The interleaver **54** buffers the encoded bits for the modulator **56**, which uses the buffered bits to form QPSK, 8QAM, 16QAM, or other modulated

symbols. The modulated symbols $57_{(0-31)}$ at the output of each channel are next passed to the TDM multiplexer **59**, which outputs a multiplexed signal **63**. Multiplier **65** spreads multiplexed signal **63** with a PN code sequence provided by PN code register **66**. Filter **67** next filters the spread signal with preferably a square-root, raised-cosine response having 25% excess bandwidth, and RF section **69** then converts the filtered signal to RF for transmission. TDMA switch **68** schedules the spread signal for transmission within downlink segment **23**.

[0033]   With reference now also to Figure 4b, the TDM multiplexer **59** receives the 32 modulated symbols $57_{(0-31)}$ from the 32 channels $48_{(0-31)}$ and multiplexes the modulated symbols via pulse generators $61_{(0-31)}$ and summer **64** to form multiplexed signal **63**. The 32 pulse generators **61** output values of 1 or 0, in a manner so that only one of the pulse generators is generating a non-zero value at any given time (i.e. pulse position) and each pulse generator has generated a non-zero value for at least one pulse position during the data time period **29**.

[0034]   It will be appreciated that by employing TDM coding, the downlink design of the invention transmits only one channel **48** at a time but at full power for each channel. By transmitting at full power for each channel over each time slot period **26** within the downlink segment **23**, the downlink of the invention operates at a much lower peak-to-average power ratio than conventional CDMA coding. Thus, the downlink design of the invention may be practiced using simpler and cheaper RF equipment, including simpler and cheaper power amplifiers. In addition, certain FCC regulations that must be complied with can also be met using such simpler equipment. Furthermore, use of nearly-continuous full power results in

394197   11

increased transmission power on the order of approximately 7.5 dB for QPSK modulation and approximately 5dB for 16QAM.

[0035]   Typically all bases would employ the same PN sequence, shifted in time for each base to reduce inter-base interference. To add a measure of randomness, and interference rejection, each base **20** may employ a different PN sequence.

Synchronization Preamble

[0036]   Referring now also to Figure 4a, a synchronization preamble is added by switch **58** to each time period **29** within multiplexed signal **63**. The preamble consists of synchronization symbols that correspond to QPSK modulation symbols for the 00 dibit. For downlink time slot periods **26**, all 32 code channels **48**$_{(0-31)}$ are preferably active for data modulation and only code channel **48**$_0$ is active during the synchronization preamble. As shown in Figure 8, a sync preamble is also added by switches **218** to each modulated channel of the remote terminals **14** (see uplink discussion below).

Parallel-to-Serial Converter

[0037]   Referring again to Figure 4a, parallel-to-serial converter **50** converts each 32-bit word within input signal **42** into a 32-bit long sequence of bits, with the first converted bit of the sequence corresponding to the least significant bit of the word. Six words are converted in succession to create a sequence of 192 bits that are input to each of the convolutional encoders **52**. For uplink transmissions **27** as shown in Figure 3a, the last 8 bits of the 192-bit sequence are set to 0 to "flush" the convolutional encoder **52** to an all-zeroes state. Similarly,

the last 8 bits of an entire downlink slot **26** (32 x 576 = 18,432 bits) are set to 0 for downlink transmissions.

Convolutional Encoder

[0038]   Referring now to Figure 5, convolutional encoder **52** is depicted in greater detail and may be a rate (r) = ½, ⅔ or ¾, constraint length (k) = 9 encoder. In each case, two bit streams **84, 86** are generated using the generator polynomials g0 = 753 (octal) and g1 = 561 (octal). Encoding rates of ⅔ and ¾ are obtained by puncturing, or deleting, certain bit positions as defined below. For rate-⅔ encoding, the second output bit of the g0 polynomial is discarded for every two input bits. Similarly, the second and third output bits of the g0 polynomial are discarded for every three input bits for rate-¾ encoding.

Interleaver

[0039]   Figure 6 shows the block diagram of the interleaver **54**, shown in Figure 4a above. The interleaver **54** includes a "ping-pong" buffer **102** large enough to store up to 1/3 slot of data per code channel. As shown in Figure 6, the interleaver **54** writes to one third-slot buffer **104** (i.e., "ping") while reading from the other third-slot buffer **106** (i.e., "pong"). After filling the "ping" buffer **104**, it is read, while writing to the "pong" buffer **106**. The interleaver **54** reorders the sequence of encoded bits from the convolutional encoder **52** so that the distance between any two consecutive encoded bits is greater than a preferred minimum after reordering. Table 2 shows the minimum distance between any two adjacent encoded bits after being reordered and grouped for modulation.

394197   13

Table 2: Minimum Distance Between Encoded Bits

Characteristic	QPSK-1/2	QPSK-3/4	8QAM-2/3	16QAM-3/4
Interleaver buffer size, encoded bits	384	256	288	256
Bits per Symbol	2	2	3	4
Interleaver buffer size, symbols	192	128	96	64
Minimum distance within symbol	12	8	12	8
Minimum distance between symbols	16	16	8	8

[0040] The preferred interleaver **54** reorders the sequence of encoded bits using a four-dimensional block interleaver. The encoded bits are written into the appropriate third-slot buffer in the order that they are encoded; i.e., g0, g1, … for rate-½ encoding; g0, g1, g1, … for rate-⅔ encoding; and g0, g1, g1, g1, … for rate-¾ encoding. This sequence is labeled as X_0 to X_{383} for QPSK-½, X_0 to X_{287} for 8QAM-⅔, and X_0 to X_{255} for QPSK-¾ and 16QAM-¾. The output sequence $\{X_k\}$ is reordered by incrementing k from k = 0 with four nested loops as follows:

a)   increment k by I, modulo M_1;

b)   when the increment by I_1, rolls over, increment k by I_2, modulo M_2;

c)   when the increment by I_2 rolls over, increment k by I_3, modulo M_4;

d)   when the increment by I_3 rolls over, increment k by 1, modulo M_4.

[0041] Table 3 defines the preferred values of the interleaver parameters and the resulting output sequence. The

serial-to-parallel converter **108** groups the reordered bits for the modulator **56**.

Table 3: Preferred Interleaver Parameters

Parameter	QPSK-1/2	QPSK-3/4	8QAM-2/3	16QAM-3/4
I_1, M_1	12, 24	8, 16	12, 36	8, 16
12, M_2	96, 384	64, 128	72, 288	64,128
I_3, M_3	24, 96	16,64	36, 72	16,64
I_4, M_4	1, 12	1, 8	1, 12	1, 8
Reordered Sequence	X_0, X_{12}, X_{96}, X_{108}, X_{192}, X_{204}, X_{288}, X_{300}, X_{24}, X_{36}, X_{120}, X_{132}, X_{216}, X_{228}, X_{312}, X_{321}, X_{48}, X_{60}, X_{144}, X_{156}, X_{240}, X_{252}, X_{336}, X_{348}, X_{72}, X_{84}, X_{168}, X_{180}, X_{264}, X_{276}, X_{360}, X_{372}, X_1, X_{13}, . . . X_{287}, X_{371}, X_{383}	X_0, X_8, X_{64}, X_{72}, X_{128}, X_{136}, X_{192}, X_{200}, X_{16}, X_{24}, X_{80}, X_{88}, X_{144}, X_{152}, X_{208}, X_{216}, X_{32}, X_{40}, X_{96}, X_{104}, X_{160}, X_{168}, X_{224}, X_{232}, X_{48}, X_{56}, X_{112}, X_{120}, X_{176}, X_{184}, X_{240}, X_{248}, X_1, X_9, . . . X_{239}, X_{247}, X_{255}	X_0, X_{12}, X_{24}, X_{72}, X_{84}, X_{96}, X_{144}, X_{156}, X_{168}, X_{216}, X_{228}, X_{240}, X_{36}, X_{48}, X_{60}, X_{108}, X_{120}, X_{132}, X_{180}, X_{192}, X_{204}, X_{252}, X_{264}, X_{276}, X_1, X_{13}, X_{25}, X_{73}, X_{85}, X_{97}, X_{145}, X_{157}, X_{169}, X_{217}, . . . X_{263}, X_{275}, X_{287}	X_0, X_8, X_{64}, X_{72}, X_{128}, X_{136}, X_{192}, X_{200}, X_{16}, X_{24}, X_{80}, X_{88}, X_{144}, X_{152}, X_{208}, X_{216}, X_{33}, X_{40}, X_{96}, X_{104}, X_{160}, X_{168}, X_{224}, X_{232}, X_{48}, X_{56}, X_{112}, X_{120}, X_{176}, X_{184}, X_{240}, X_{248}, X_1, X_9, . . . X_{239}, X_{247}, X_{255}

Modulator

[0042] The modulator **56**, shown in Figure 4a above, takes the interleaved bits in groups of 2, 3, or 4 bits, and maps each group to a unique I-Q phasor as defined by the constellations **150** in Figure 7. For QPSK modulation, the modulator takes interleaved bits in groups of two and maps the first of the two reordered bits to the most significant bit of the in-phase (I) component and the second to the most significant bit of the quadrature-phase (Q) component. The least significant bit of both the I and Q are set to "0" for

QPSK, and the four valid constellation points consist of the corners of the square formed by all constellation points **150**. For 16QAM modulation, the first and second reordered bits are mapped to the most and least significant bits of the I component, respectively; the third and fourth bits are mapped to the most and least significant bits of the Q component. For 8QAM modulation, the second and first reordered bits are mapped to the most and least significant bits of the Q component, respectively; the third and the complement of the first bits are mapped to the most and least significant bits of the I component.

[0043]   When the modulator output is converted to RF after filtering, the I component is modulated with a carrier signal that is advanced 90 degrees before the carrier signal that modulates the Q component.

PN-Code Spreader

[0044]   Referring again to Figure 4a, the multiplexed signal **63** is further modulated by a long pseudo-random noise (PN) code sequence **66**. The long PN code is preferably a maximal linear binary code of length $2^{20}-1$, restarted at the beginning of each successive frame **22**. In the preferred embodiment, the frame duration is 7.5 milliseconds but can be extended by a factor of four to 30 milliseconds. The chipping rate is 20.75 Mchip per second, and the number of chips in the longest frame is 622,500 chips. Hence, $2^{20}-1$ is the shortest maximal sequence to insure unambiguous sync searching over the frame interval.

Uplink

[0045]   Figure 8 depicts the preferred transmission logic diagram **201** for one remote terminal **14**, as shown in

Figure 1. The remote terminal transmission logic differs from the base **20** transmission logic in several significant aspects, including the use of orthogonal CDMA (O-CDMA) coding and the lack of PN spreading of the transmitted signal. With greater particularity, each remote terminal **14** may be assigned one or more channels **208**$_{0-n}$ on which to transmit data to the base **20**, depending upon the amount and type of data that needs to be transmitted to the base. Upon initiating communication with the base, the remote terminal indicates its data transmission needs, and the base assigns the remote terminal a number of channels upon which to transmit based upon the needs of the requesting remote terminal as well as all other active remote terminals.

[0046]   Similar to the base **20**, the data stream **200** to be transmitted by each remote terminal **14** is a stream of time division multiplexed packets. The stream is demultiplexed by demultiplexer **204** into one or more code channels **208**$_{(0-n)}$ and processed through FEC **212** and modulator **216** in each code channel. The other processing steps are omitted for simplicity, but it is understood that the process is highly similar to that employed by the base **20** transmission logic. Once each word has been modulated in a respective code channel, a sync preamble is added by switch **218** and the modulated signal is then spread in multiplier **220** with an orthogonal (O) code **222**. The O-codes used to spread the channels are orthogonal to each other, and thus exhibit zero cross-correlation for a resultant lack of inter-channel interference. The modulated, orthogonal signals are next summed in summer **230** and the resultant modulated signal **240** is enabled to be transmitted by TDMA switch **243** and filtered **244** before being passed to RF section **241** for transmission to the base **20**.

[0047]   The O-code sequences used to spread the modulated signal on each channel are relatively short (32 bits in the preferred embodiment). It is important to note that PN sequences used in conventional CDMA systems do not typically cross correlate or average to zero within such a short period but rather typically average to zero over relatively much longer periods of time. Thus, further spreading such short orthogonal sequences with a much longer PN sequence, as is typically done in conventional CDMA systems would add a rather limited measure of randomness or "noise" to the transmitted signal and would do little to aid in the rejection of interference.

[0048]   For uplink transmission, a remote terminal **14** may use up to 32 code channels **208**. Each code channel is active for both the synchronization preamble and data-modulation portion of a time slot **27**. Up to 32 remote terminals **14** may transmit on different orthogonal code channels **208** during a time slot interval. In an alternative embodiment, remote terminals may be restricted to only one code channel to minimize peak transmitter power.

[0049]   The O-codes **222** can be generated in real time, but are preferably calculated and stored in memory by both the remote terminals and the bases. Various options are available in selecting O-codes. Walsh codes are perhaps the best-known in the art, and are a class of orthogonal binary sequences of length n, for n equals any power of 2. However, Walsh codes do not have optimum characteristics for use with the invention, because they actually exhibit a certain amount of cross correlation when the channels are phase shifted in time.

[0050]   Thus, in one preferred embodiment, O-code sequences are generated from a maximal length sequence by the

method described below. For generating O-sequences of length 32, 6 sequence matrices may be generated. With reference to Table 4, we begin with a maximal length sequence m1, m2 … m31, and add a zero at the end. Next, each successive row is filled in by shifting the sequence to the left, m2, m3 … m1, and keeping the zero in the last position. This is continued until the 31st row has been filled in m31, m1 … m30, and then the last row is filled in with zeros.

Table 4. Maximal length sequence O-code generation.

m_1 m_2 m_3 m_4 m_5 m_6 m_7 m_8 m_9 m_{10} m_{11} m_{12} m_{13} m_{14} m_{15} m_{16} m_{17} m_{18} m_{19} m_{20} m_{21} m_{22} m_{23} m_{24} m_{25} m_{26} m_{27} m_{28} m_{29} m_{30} m_{31} 0

m_2 m_3 m_4 m_5 m_6 m_7 m_8 m_9 m_{10} m_{11} m_{12} m_{13} m_{14} m_{15} m_{16} m_{17} m_{18} m_{19} m_{20} m_{21} m_{22} m_{23} m_{24} m_{25} m_{26} m_{27} m_{28} m_{29} m_{30} m_{31} m_1 0

m_3 m_4 m_5 m_6 m_7 m_8 m_9 m_{10} m_{11} m_{12} m_{13} m_{14} m_{15} m_{16} m_{17} m_{18} m_{19} m_{20} m_{21} m_{22} m_{23} m_{24} m_{25} m_{26} m_{27} m_{28} m_{29} m_{30} m_{31} m_1 m_2 0

.   .   .   .   0

.   .   .   0

.   .   0

.   0

m_{31} m_1 m_2 m_3 m_4 m_5 m_6 m_7 m_8 m_9 m_{10} m_{11} m_{12} m_{13} m_{14} m_{15} m_{16} m_{17} m_{18} m_{19} m_{20} m_{21} m_{22} m_{23} m_{24} m_{25} m_{26} m_{27} m_{28} m_{29} m_{30} 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

[0051] For generating O-sequences of length 32, 6 sequence matrices may be generated by this method. In one preferred embodiment, all six of these sequences are generated and stored in memory by each remote terminal and each base. Each word coded by each channel **208** is modulated by a different one of these six O-code sequences, in accordance with a predetermined, pseudo-random sequence. In this manner, each symbol is spread with a different O-code in a pseudo-random, noise-like manner that further enhances the interference rejection of the modulated transmission signal. It must also be noted that maximal length sequences are themselves pseudo-random, and thus noise-like, and thereby further introduce a degree of randomness and interference

rejection in the symbols encoded with O-codes derived from them. For all of the above reasons, the interference rejection exhibited by the uplink design of the invention does not require the additional complexity and expense of being further spread by PN coding.

[0052]   O-code sequences for use with the uplink of the invention may also be generated by using the Quadratic Residue sequence and its inverse. Thus, in this preferred embodiment, each remote terminal **14** and each base station **20** may each store eight sets (six sets generated from maximal sequences and two sets generated from quadratic residue sequences) of 32 sequences that are self-orthogonal; i.e. the cross-correlation between any two sequences of a set is zero.

[0053]   In the first embodiment, a base station and its remote terminals are restricted to use only one of the eight sets. A system planner assigns which set each base station is to use. This scheme offers enhanced inter-base interference rejection because the cross-correlation between sequences from different sets is less than the cross-correlation between sequences from the same set, when there is a time shift (due to the propagation time between bases). The operation within each base is now described.

[0054]   When a remote terminal **14** desires to transmit information on a reserved channel, it first requests a channel assignment from the base **20** using a contention-access channel. The base **20** responds with an assignment that includes both the TDMA time slot(s) granted and the logical channel(s) to be used during each TDMA time slot granted. A remote terminal may be assigned multiple channels during an individual TDMA time slot and each channel can be used to send 600 (for QPSK, rate-1/2) consecutive symbols during the time slot.

[0055]   The remote terminal converts each logical channel assignment into a single physical channel that consists of a sequence of 600 rows (for QPSK) from the orthogonal set. Successive rows from the orthogonal set are chosen using a pseudo-random mapping. "Randomly" picking different rows for each of the 600 symbols greatly simplifies remote to base synchronization.

[0056]   The pseudo-random mapping changes every 32 chip-intervals (a single symbol), and repeats at the frame rate. The base and all remote terminals use the same pseudo-random mapping so that the base station can reconstruct the information. In the example shown in Table 5, the base has assigned one logical channel to remote terminal #1, two logical channels to remote terminal #2, and one logical channel to remote terminal #3. The logical-channel assignments made by the base is constant during the TDMA slot, and the pseudo-random mapping changes the physical, or actual, channel sequence within the slot.

Table 5. Physical Channel Assignments During One TDMA Slot

32-chip interval	Remote #1 Phy. Chan.	Remote #2		Remote #3 Phy. Chan.
		Phy. Chan.	Phy. Chan.	
1st	13	21	2	11
2nd	22	6	15	31
3rd	1	31	10	12
4th	16	17	5	3
5th	29	23	18	24
600th	3	14	31	11

[0057]   In an alternative embodiment, each remote and base station also stores the eight sets of 32 self-orthogonal sequences, as described previously. However, in addition to pseudo-randomly mapping the logical-to-physical channel

assignments as above, in this embodiment each remote terminal also pseudo-randomly selects among the eight O-CDMA sequence sets. This selection is performed at the same time as the logical-to-physical mapping; i.e. every 32 chip-interval.

[0058]   This embodiment provides inter-cell interference rejection that is nearly as good as the previously described embodiment and does not require a system planner to coordinate the cell assignments. An illustrative example is shown in Table 6.

Table 6. Physical Channel Assignments During One TDMA Slot

32-chip interval	Remote #1		Remote #2				Remote #3	
	Seq. Set	Phy. Chan.	Seq. Set	Phy. Chan.	Seq. Set	Phy. Chan.	Seq. Set	Phy. Chan.
1st	0	13	0	21	0	2	0	11
2nd	5	22	5	6	5	15	5	31
3rd	2	1	2	31	2	10	2	12
4th	7	16	7	17	7	5	7	3
5th	4	29	4	23	4	18	4	24
600th	1	3	1	14	1	31	1	11

[0059]   Of course, simpler alternatives are also within the scope of the invention. For example, a single set of 32 orthogonal sequences may be provided for use by each network of remote terminals.

Uplink Synchronization Procedure

[0060]   Referring now to Figure 8, to maintain orthogonality among the uplink code channels 208, the remote terminals 14 must synchronize their uplink signals 27 so that the signals from all remote terminals arrive at the base station 20 aligned in time. This enables the base station to (i) correlate to the sequence, and (ii) eliminate the signals arriving from other remote terminals (i.e. all remote transmitted sequences arrive at the same time so that the

orthogonality of the sequence can be used to eliminate interference between remote terminals). In the preferred embodiment, the base 20 measures the timing error of each uplink signal 27, and then sends the error information in a control message during the downlink segment 23 to the corresponding remote terminal 14. The remote terminal 14 uses the error information to adjust the time of its next transmission so that it arrives at the base 20 at the correct time. In order to reduce the frequency of making adjustments, each remote terminal 14 sets the frequency of its transmitting code clock to be equal to the downlink code clock frequency. Timing errors can be measured using the delay-lock discriminator method on the synchronization symbols corresponding to the uplink code channel and time slot.

[0061]   Uplink synchronization is also aided by pseudo randomly choosing different orthogonal codes for each symbol transmitted, as described previously. This is the case because before starting the synchronization process, the time uncertainty, or interval of time in which the correct synchronization time exists, is larger than the duration of one sequence. In fact, a unique pattern with duration of one slot (or 600 sequence intervals; i.e. 600x32 chips) is preferred to identify the correct synchronization time. The preferred method of generating this pattern is to pseudo-randomly map the logical-to-physical channel because this can be implemented in hardware relatively simply.

[0062]   Additional advantageous features of the invention include the use of high-order modulation methods leads to many bits being packed into each cycle of available spectrum; using power control on the uplink to operate each remote terminal 14 at no more than the amount of power needed

for the given link conditions; synchronizing the downlink and uplink segments among all cells to reduce interference between adjacent bases **20**; providing each base with a six-sector antenna to increase capacity by reusing frequencies at each adjacent base; and using high-gain directional antennas to minimize interference.

[0063]   Having now described the invention in accordance with the requirements of the patent statutes, those skilled in this art will understand how to make changes and modifications in the present invention to meet their specific requirements or conditions. Such changes and modifications may be made without departing from the scope and spirit of the invention as set forth in the following claims.